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THE VALUE OF 'HAVING A GO': TRIALLING A PROJECT-BASED LEARNING ACTIVITY TO INFORM CURRICULUM DESIGN

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ABSTRACT

Active, student-centred pedagogies such as project-based learning (PjBL) can offer significant potential for engaging undergraduates with complex sustainability issues. Driven by institution-wide curriculum changes, and informed by educational theories and evidence from previous studies, a trial PjBL activity was designed and delivered on three separate occasions, to three different student groups, at a UK university. In these trials, students from geography, Earth, and environmental science (GEES) programs worked in small (5-6 people), multiple discipline teams to explore a single research question focused on a global sustainability issue. The perceptions and experiences of the trial participants (students and faculty) were investigated using data from surveys and interviews, and the findings applied to designing a new, multiple disciplinary module focused on energy and climate change. In general, all participants engaged positively with the PjBL approach, although issues around the nature and extent of support available to the students and appropriate methods of assessing PjBL outputs, emerged as requiring further consideration. The findings demonstrate that a single research question need not constrain the approach that students take when completing a PjBL activity and identify clear potential benefits in terms of developing students' wider professional skills. This study also highlights the value to curriculum developers in trialling new pedagogic approaches, as the opportunity to 'have a go' enabled potential issues for learners and instructors to be identified, and mitigated, prior to the final module design and implementation.

Keywords: Project-based learning, Sustainability education, Curriculum design, Evaluation, UK higher education

INTRODUCTION

This study investigates the pedagogic potential of project-based learning (hereafter referred to as PjBL) in delivering sustainability education to first-year undergraduates (freshmen) learning in a multiple disciplinary context. Sustainability education is widely accepted as a key response to meeting the challenges of balancing human needs with care for the global environment in the twenty-first century, and its importance in higher education is recognised and supported at multiple scales (e.g. UNESCO, 2014; United Nations, 2016). In the UK, the Higher Education Academy (HEA) and the Quality Assurance Agency (QAA) have produced guidance for educators at undergraduate and postgraduate level on incorporating sustainability into teaching and learning (QAA, 2014a), and research suggests that a large proportion of UK students wish to see sustainability actively incorporated and promoted by universities (Drayson, 2015). In the US, the importance of incorporating sustainability into all levels of education is being increasingly recognised, with recent initiatives such as "Sustainability Improves Student Learning" contributing to the embedding of sustainability into wider STEM curricula (Metzger, Blockstein & Callahan, 2017). Despite these initiatives and guidance, however, designing and delivering instruction that engages undergraduates with complex sustainability issues can be challenging.

The study took place at a single UK university, and was instigated in response to institution-wide curriculum changes which involved the introduction of immersive, project-based modules into the first-year curriculum. These modules are delivered intensively (i.e. as a 'standalone' without other parallel modules running alongside) over a four-week period, and have required a radical change in pedagogic style from single discipline-focused teaching and learning provision, to a student-centred approach capable of accommodating learners from multiple disciplines. This approach is unusual in UK undergraduate education where,

for the duration of their degree program (normally three years), students typically receive instruction only in the academic subject for which they enroll, and rarely encounter learners from different subject areas in an academic context. Likewise, faculty typically teach only to single disciplinary student cohorts. This is a very different model to the North American system where, over a four-year program, students take courses covering a broad range of subjects before deciding on their major at a later point in their studies.

The aim of this exploratory study was to inform the design and delivery of a multiple disciplinary module focused around climate change and energy, and involved students and faculty from geography (human and physical), Earth science, and environmental science programs (hereafter referred to as 'GEES'). A broad range of disciplines are represented in the PjBL literature (Harmer and Stokes 2014), but the application of PjBL specifically to multiple disciplinary teams of GEES students has not, to date, been reported. This study therefore offers an interesting opportunity to investigate the perceived benefits afforded to, and challenges faced by, learners and instructors from cognate, yet distinct, disciplines when applying a PjBL approach to complex, real-world sustainability problems. The following specific questions were addressed:

1. What are the characteristics of PjBL activity design appropriate to the delivery of sustainability education to students learning in multiple disciplinary GEES contexts?
2. What types of support are required by first-year students engaging in multiple disciplinary PjBL?
3. To what extent are extracurricular trial activities useful in informing curriculum design and delivery?

We present a rich description of the process of designing and implementing a specific intervention (a single trial PjBL activity, delivered three times), together with empirical evaluation intended to inform future curriculum design. Critical reflection on the process, and

its subsequent embedding in the undergraduate curriculum, provides valuable insight into the wider potential of piloting of new approaches (i.e. using trial activities) in informing curriculum development.

A note on terminology: The initials PBL are commonly used in the literature to represent problem-based learning. The approach applied in this study is project-based learning which, although sharing many similarities with PBL, is not the same. The 'j' is therefore inserted to avoid confusion with problem-based learning. A discussion of the respective pedagogic characteristics of PBL and PjBL can be found in Harmer and Stokes (2014). Further, although the term 'interdisciplinarity' is widely applied in higher education, there is a lack of consensus about its precise meaning (Choi & Pak, 2006), and examples exist in the PjBL literature of sustainability-focused studies referred to as 'interdisciplinary' (e.g. Brundiers & Wiek, 2013), 'multidisciplinary' (e.g. Nation, 2008) and 'transdisciplinary' (e.g. Stauffacher et al., 2006). Choi and Pak (2006) present a useful and comprehensive overview of the various definitions applied to these terms in the literature and propose that "when the exact nature of a multiple disciplinary effort is not known, the specific terms 'multidisciplinary', 'interdisciplinary' and 'transdisciplinary' should be avoided, and the general term 'multiple disciplinary' used instead" (p.359). With respect to cited studies we adhere to the terminology used by their original authors, but have chosen to refer to this study as 'multiple disciplinary' because the exact nature of the interaction between students while participating in this study cannot be specified.

PjBL in sustainability education

Contemporary issues around sustainability and sustainable development are complex, contested, and cross traditional disciplinary boundaries (e.g. Stauffacher, Walter, Lang, Wiek,

& Scholz, 2006; Nation, 2008; UNESCO, 2014; Kricsfalusy, George, & Reed, 2016; Metzger et al., 2017). Often referred to as 'wicked' problems (e.g. Rittel & Webber, 1973; Levin, Cashmore, Bernstein & Auld, 2012), understanding these issues in terms of their causes, impacts and potential solutions poses some interesting challenges for undergraduates, requiring them to develop and apply skills beyond simply enhancing their factual knowledge (e.g. Sterling, 2001). Sustainability education therefore lends itself well to student-centred pedagogic approaches which facilitate active learning, and promote the development of skills necessary to tackle issues which transcend disciplinary boundaries (Barth & Burandt, 2014; UNESCO, 2014). PjBL is particularly well suited to meeting these requirements. Most significantly, it requires students to actively collaborate with both peers and faculty to construct new knowledge (Blumenfeld, Krajcik, Marx, & Soloway, 1994; Helle, Tynjälä, & Olkinuora, 2006), while also drawing on their prior knowledge and experience, in order to collectively explore and solve real world problems (Stauffacher et al., 2006). PjBL facilitates learners to become autonomous learners, and offers a more democratic style of education than the traditional, didactic approaches typically associated with higher education (Morgan, 1983; Helle, Tynjälä, & Olkinuora, 2006).

The focus on authentic, real world issues and tasks that is characteristic of PjBL in sustainability education (e.g. Nation, 2008; Wiek, Xiong, Brundiers, & van der Leeuw, 2014) offers clear benefits for undergraduates. Most importantly, it provides a link between academic learning and practical application, enabling learners to explore multiple potential solutions (Kahn & O'Rourke, 2004), and encouraging them to think beyond the boundaries of their own disciplines, e.g. by considering societal as well as scientific implications (e.g. Nation, 2008). While it has successfully been applied in some monodisciplinary contexts, notably in engineering, (e.g. Lehmann, Christensen, Du, & Thrane, 2008; Bielefeldt, 2013; Du, Su, & Liu, 2013; Jollands & Parthasarathy, 2013), PjBL is more frequently encountered

in multiple disciplinary contexts – perhaps not surprising, as a key characteristic of this approach is the integration of multiple types of knowledge (Brundiers & Wiek, 2013).

Commonly reported outcomes from multiple disciplinary PjBL studies include positive impacts on learners' knowledge, skills and attitudes, together with wider social benefits. For example, environmental consultancy projects undertaken by multidisciplinary teams of undergraduates investigating sustainable waste management solutions for a new-build university in Vietnam helped students to develop both their professional skills, and cultural awareness (Meehan & Thomas, 2006), while investigations undertaken by teams of graduate and undergraduate student volunteers into the live turtle trade in China contributed to the work of conservationists, and helped to raise awareness of the issue among the public (Cheung & Chow, 2011). Nation (2008) explored PjBL as a pedagogic approach for graduate geography students engaged with sustainable development projects, and facilitated in an interdisciplinary context. While identifying some of the challenges associated with working across disciplinary boundaries, e.g. institutional or disciplinary barriers, the study also highlighted key advantages of involving students in real world problems such as developing, and applying, critical thinking and problem-solving skills.

PjBL is also well placed to foster graduate attributes by providing students with the opportunity to develop skills and competencies valued by employers and typical of professional practice (Jolland & Parthasarathy, 2014). Individual skills such as project management, written and oral communication, and leadership are complemented by collaborative skills, specifically those relating to team working e.g. negotiation, conflict management, and managing schedules (e.g. Kricsfalusy et al., 2016), all of which are critical to problem solving in multiple disciplinary contexts.

FRAMEWORKS FOR PEDAGOGIC DESIGN AND DELIVERY

Theoretical framework

Three theories of learning informed the design of the trial PjBL activities described in this study: 1) experiential learning; 2) constructivism; 3) transformative learning. Experiential learning is the process whereby experience is transformed into new knowledge and understanding through a process of experiencing, reflecting, generalising and applying (Kolb, 1984). Experiential approaches such as PjBL help students to make sense of complex issues such as climate change (e.g. Coleman, Murdoch, Rayback, Seidl, & Wallin, 2017), and provide them with opportunities to develop collaborative learning skills (e.g. Brundiers & Wiek, 2013; Kricsfalusy et al., 2016). These approaches are further underpinned by constructivism, whereby social interaction, e.g. through small-group work, facilitates the construction of new knowledge and understanding (e.g. Stauffacher et al., 2006; Armstrong, 2011; Brundiers & Wiek, 2013). Extending these ideas yet further, transformative pedagogies expose students to learning experiences which challenge their existing ideas and beliefs, and hence empower them to change their worldviews (Sipos, Battisi & Grimm, 2008; Palma & Pedrozo, 2016). Emerging originally from Mezirow's work on adult education (1978, 1997), the transformative potential of PjBL has been recognised both in relation to higher education (von Kotze & Cooper, 2000) and sustainability education (Sterling, 2010-11).

Practical framework

Brundiers and Wiek (2013) present a practical framework for the design of problem-based and project-based learning courses in sustainability education in higher education based on a comparative study of courses globally. Although they do not explicitly discuss multiple disciplinary contexts, the outcomes from their evaluation highlight the importance of PjBL in

addressing issues around sustainability, and identify the following key characteristics of PjBL as a pedagogic approach:

- Learners engage with real world tasks
- Student-centred, small group activities
- Simulates authentic contexts, e.g. professional environments
- Involves processing information from multiple sources
- Teachers act as facilitator or mentor, and resource guide
- Lends itself to both formative and summative assessment

These characteristics informed the design of the trial PjBL activity described in this study. While the importance of providing choice over topic area is emphasised in much of the PjBL literature (Harmer & Stokes 2014; 2016), this approach has not been universally applied with respect to sustainability education (Brundiers & Wiek, 2013). Also, there is no apparent consensus in the literature around ideal group size for PjBL, or how groups working on PjBL projects in any discipline, including sustainability, should be selected (Harmer and Stokes, 2014 and references therein). The student participants' perceptions of choice around project topic, and group selection, are further discussed in Harmer and Stokes (2016).

STUDY CONTEXT, POPULATION AND SETTING

This study took place at a single public university in the UK over the period April–December 2014. The university has over 23,000 students and is located on an urban campus in a coastal city. Full ethical (IRB) approval was gained prior to commencing the study. First year GEES students select from a limited number of immersive modules designed and delivered by the School of Geography, Earth and Environmental Science. The modules take

218 place at the beginning of the second semester of the students' first academic year, and are the
219 only elective module in that year. As well as enhancing knowledge and understanding, these
220 modules also aim to develop students' abilities in thinking critically about complex issues
221 relating to sustainability and/or natural hazards, and to develop their group working skills by
222 working in multiple disciplinary teams. The five other (compulsory) modules that students
223 complete during their first academic year all take place within their own discipline, i.e. the
224 students learn with the same group of peers, and are taught by faculty from within their own
225 subject area. This is therefore the only opportunity for first-year students to engage
226 academically with peers and faculty from different academic disciplines.

227 A preliminary workshop run by the first author in April 2014 explored the perceived
228 benefits and challenges of multiple disciplinary PjBL from the perspective of GEES students
229 and faculty (Harmer and Stokes, 2016). Using the outcomes from this workshop, a trial PjBL
230 activity was developed (July–September 2014), run over three iterations with three different
231 multiple discipline student groups (October–November 2014), and evaluated with respect to
232 faculty and student participants' perceptions of the PjBL process and outcomes (November–
233 December 2014). Activities were extracurricular for all participants, i.e. they took place
234 outside of the main academic timetable, and participation was entirely voluntary. The full
235 project team comprised: the project lead (first author, geoscientist with expertise in
236 curriculum development and education research), a dedicated researcher-evaluator (second
237 author, human geographer with expertise in social research), two environmental scientists in
238 an academic tutor role (one with expertise in curriculum design and innovation, the other
239 intending to lead the new multiple disciplinary module focused on climate and energy
240 change), and one further member of GEES faculty in a facilitator/support role (physical
241 geographer with expertise in curriculum design and innovation).

The timing of confirmation of the funding award for this project meant that student participants for the trial activities needed to be recruited, and the study initiated, within a very short timescale. In addition, time constraints for running the trial PjBL activities meant that it was important to recruit students who would be motivated to complete the trial. For this reason, purposive (i.e. targeted) sampling was used to recruit student participants, whereby faculty members acting as personal tutors to first-year students recommended individual students that they considered sufficiently motivated to engage with an extracurricular project. As a result, 31 students from an overall first-year cohort of 420 were emailed a personal invitation to participate in the study. The reward for participation was free enrollment on an institutional program which formally recognises extracurricular achievement, and for which a fee of £25 is normally charged. Following this initial approach, 16 students registered for BSc or BA geography (n=3), BSc geology (n=7), and BSc environmental science (n=6) programs volunteered to participate. Seven students were male, and nine female. All were aged between 19 and 21 at the time of the study, and all were Caucasian. While this method of targeted sampling proved successful in recruiting participants within a short timescale, the resulting sample was not representative of the overall student population in terms of motivation, attitude and academic ability, and this should be recognised as a limitation of the study. Further, at the time of participation, the students were at the beginning of their second year of academic study. While this meant that they were more academically advanced than the target student population, they were able to critically reflect on how this particular pedagogic approach might be experienced within the wider student cohort.

METHODS

Design and delivery of the trial PjBL activities

The project topic was defined by a single research question, compiled by the project academic tutors:

To what extent does coal with carbon capture and storage (CCS) represent a sustainable means of electricity production?

This question addresses a complex and ill-defined sustainability issue and was considered broad enough to engage students from across the GEES disciplines, with interests ranging from political geography to hard-rock geology, yet sufficiently focused to generate some meaningful output within the limited timescale of the project. The three trial groups were pre-defined to ensure a mix of specialist subject knowledge and genders, as might be encountered in a professional team setting, with the number of participants (5–6) reflecting the intended group size in the final modules.

Each group was required to undertake preliminary investigation into the research question, and to summarize their findings, together with recommendations for further research, on a group mind map. The purpose of this mind map 'assessment' was to gain insight into how the students organised information and structured their emergent, collective knowledge during the trial PjBL activity, rather than to quantitatively measure the students' knowledge and understanding. Mind maps were selected for this purpose due to their potential to reveal students' strategies for approaching the task, i.e. how a complex issue is broken down, and new concepts linked together (Davies, 2011). In the context of a full module (i.e. running over four weeks), this mind mapping constitutes the initial phase of a more protracted research exercise, and forms the basis for both formative and summative assessment. This is discussed further at a later point in the paper.

Each trial PjBL activity ran for a three-week period outside of the normal curriculum, and individual trials were initiated at two-week intervals (i.e. the second trial began two weeks after the beginning of the first trial etc.). During this period students were each expected to spend in the region of 12–15 hours working on the project, in either a group or an individual capacity. This time commitment was informed by 1) the amount of time that students would be expected to spend on the initial project 'scoping' phase during a full four-week module, and 2) recognition that students were participating in these trials voluntarily, in addition to their timetabled activities and associated commitments. Students were issued with a suggested program of activity (Table 1), but ultimately were expected to plan and organise their own time.

The trial PjBL activities began with an hour-long introductory session in which students were given general instructions about completing the activity, and information about the project evaluation. This was followed by a brief presentation by one of the academic tutors which introduced the research question, and provided some background information relating to key concepts around the sustainability of coal as an energy source. Recognizing the challenges faced by students when undertaking group work (e.g. Stauffacher et al., 2006; Brundiers & Wiek, 2013) the final part of the session involved the second academic tutor introducing group working and mind mapping techniques, and facilitating an initial brain-storming activity around the project topic, in order to initiate the team building process. A range of resources to support the students' investigations were made available in a variety of formats through a dedicated virtual learning environment site (Moodle). These included academic papers and reports, narrated PowerPoint slides of the presentations given by the tutors in the initial session, and links to YouTube videos on CCS. The students were then left to work independently, to identify and integrate information from a range of sources, and compile their mind map.

The trial PjBL activities concluded at the end of the third week with an informal presentation involving a question and answer session between the students and the project team about their findings in relation to the research question, and their experiences of participating in a multiple discipline PjBL activity. Although no formal contact time was scheduled during the three weeks of the trial, students were encouraged to proactively contact the academic tutors or project staff if they encountered any issues or needed additional help.

Evaluation of the trial activities

The trial PjBL activities were evaluated using a mixed methods approach, with both qualitative and quantitative data contributing to the evaluation process (Robson, 2011). The following data were collected by the researcher-evaluator (second author) for the purposes of evaluation:

- *Surveys:* all students completed a brief survey compiled by the researcher-evaluator and designed to capture their perceptions of the introductory session. The survey consisted of four Likert-scale and two open questions, and was implemented at the end of the session.
- *Group discussions:* discussions taking place during the final presentation session between the students and project staff were audio recorded and transcribed. These reflective discussions focused on the students' findings from their research, their experiences of undertaking multiple disciplinary project work, and their perceptions of PjBL as a pedagogic approach in sustainability education. The content of the mind maps was informally discussed, but not formally analysed or assessed, because the focus of the evaluation was to gain insight into the PjBL process.

- *Individual interviews:* semi-structured, face-to-face interviews were carried out with student participants in the days immediately following their respective presentation session, and with the academic tutors at the end of all three trial PjBL activities (interview questions summarized in online supplement A). Interviews lasted between 20 and 40 minutes and further explored participants' perceptions of PjBL, together with their motivations for taking part in the study, and their reflections on the outcomes from both an academic and personal perspective. All interviews were audio recorded and transcribed.

Survey data were subjected to simple quantitative analysis using Excel. Transcripts from the group discussions and interviews were imported into NVivo and the content thematically analysed to identify the key emergent themes (Hsieh & Shannon, 2005; Charmaz, 2014). Following an initial thorough reading of each transcript, key words or phrases which appeared to capture participants' perceptions or critical aspects of their experience were assigned preliminary codes. These codes were then reviewed and either combined or further refined to identify the main emergent themes (summarized in online supplement B). Preliminary coding of one transcript was undertaken by both the researcher-evaluator and project lead, and the resultant codes compared and further discussed to identify and agree the key themes emerging from the analysis. All remaining transcripts were then coded by the researcher evaluator and verified by the project lead.

Limitations

While the approach reported here optimised the resources and time available, it also introduced limitations which should be addressed in any future study of this type. Timing constraints placed restrictions on the design and delivery of the trial PjBL activities, thereby

limiting the extent to which findings reported here can be generalised to other contexts. Most significantly, the study population was small, and the sampling strategy resulted in a 'best case scenario' in which all students were motivated to participate and engage. However, although the lack of assessment pressure could have benefitted the students' engagement by making them more open to trying new approaches, they could equally have imparted less effort simply because the activity was not assessed. Further, learning was undertaken outside of the normal curriculum when students were experiencing multiple demands on their time and attention from other modules, and timetabling constraints made it difficult for them to identify convenient times to meet. Therefore, while they all engaged with the trial activities to some extent, this was likely not a true reflection of their potential engagement with a 'real' immersive module.

EVALUATION FINDINGS AND DISCUSSION

The findings from the evaluation of the trial PjBL activities are presented and discussed with respect to the main research questions.

What are the characteristics of PjBL activity design appropriate to the delivery of sustainability education to students learning in multiple disciplinary GEES contexts?

Findings from Likert scale questions in the post-introduction survey indicate that, in general, the students felt that they understood the task and were clear about what was expected of them (Figure 1). Responses to the open question "what did you like most about the introductory session?" revealed that the students liked the informal, relaxed way in which the

introductory session was conducted, and welcomed the opportunity to engage in an activity with other group members. Comments included:

> *I enjoyed the Post-it game/activity as it encouraged us to work as a group and really listen to other peoples' ideas. (Group 1)*

> *Was open, fairly informal, more personal. (Group 3)*

Responses to the accompanying question "what aspects of this session do you think could be improved?" indicated that some clearer direction was necessary around how to initiate the task. Comments included:

> *Maybe more pointers on starting areas. Advice on ways to work. (Group 3)*

> *More information about the topic would have been useful, but I assume all of the information is on the Moodle site, which was made available to us beforehand. (Group 2)*

Overall, the positive comments mainly concerned social aspects of the session, while the negative comments mainly concerned the academic content. This highlights the importance of making explicit the academic requirements of the task and expectations of the students prior to them embarking on independent study (Gavin, 2011; Stauffacher et al., 2006) while also acknowledging that some students may require more pre-activity support than others.

Critical aspects of PjBL design include the project topic (i.e. research question), social context, and intended outcome (Brundiers & Wiek, 2013). Although much of the PjBL

literature advocates choice over project topic, previous studies have shown this to be problematic for some students (Gibbes & Carson, 2013; Butler and Cristofili, 2014). In this study, despite being presented with a single, pre-defined research question rather than choosing their own topic, each of the three groups approached the activity differently in terms of how they allocated and organised tasks, and the format in which they presented their findings. In the first trial, the students divided the topic and allocated tasks based on perceived fair division of labour, but gave relatively little consideration to the 'bigger picture' and how their individual findings linked together. Their findings were presented as a paper-based mind map. The group undertaking the second trial chose to allocate tasks based on group members' academic disciplines (i.e. specialist knowledge), as this was perceived to both optimise the available time, and maximise the likelihood of achieving good marks. They also presented their findings as a mind map, but in an electronic format. In the final trial, the students chose to individually research specific aspects of the topic, and to integrate their findings under the three broad themes of social, economic, and environmental issues. They engaged with knowledge outside of their own academic disciplines, and presented their findings as a Venn diagram embedded in Prezi presentation, which they considered to better capture the main points emerging from their research, and the links between them. These findings suggest that a single research question relating to a sustainability issue can successfully generate a range of approaches and output styles among multiple disciplinary teams of first-year GEES students. This is an important finding; it shows that teams of GEES students are capable of 1) generating multiple potential solutions to real world issues, and 2) demonstrating autonomy, even when choice is limited.

The exact phrasing of the question raised issues among both the students and the tutors, however, which in turn raises an interesting dilemma about how prescriptive questions relating to complex, wicked problems should be. For instance, one of the tutors felt that

440 further information on the core characteristics of sustainably might have been helpful in
441 providing the students with a more robust scaffold for the project:
442
443 *If we had a question that was framed in the way it was, with sustainability as one*
444 *central theme, then I think there is information which we can provide on what*
445 *sustainability is, because two groups got it and one didn't and they all – because*
446 *conceptually it is a kind of…it's quite loose… (Tutor 2)*
447
448 While some students clearly found the lack of structure challenging, leaving them to grapple
449 with an ill-defined question encouraged them to think for themselves and learn
450 independently, and ultimately did not appear to limit their ability to produce relevant output.
451 Further, irrespective of the extent to which they engaged with the subject matter beyond their
452 own disciplinary boundaries, the students recognised the potential transformative impacts that
453 result from exposure to other ways of thinking when approaching a real-world issue with
454 inter-linked social, environmental and economic dimensions. This exposure to other
455 perspectives prompted some critical reflection on the limitations of learning purely within
456 their own disciplinary area, and the benefits of co-learning with peers from other subjects,
457 thus emphasising the benefits of PjBL in terms of multiple disciplinary engagement and
458 encouraging more holistic thinking around complex sustainability issues (Sterling, 2001;
459 Meehan & Thomas, 2006):
460
461 *These guys have a totally different outlook and I remember at the first session I was*
462 *saying: "And what about…?" and when we [were] talking about mountain top removal*
463 *I was saying: "Look at the habitat destruction" and you [other students] were like: "I*
464 *didn't even think of that as a point." (Group 1)*

The assessment of group activity is always contentious as students feel strongly that their grade should reflect fairly their individual, as well as their shared, input (Gibbs, 2009). The students perceived mind-mapping to be a useful means of formatively assessing outcomes from the trial PjBL activity, but expressed mixed views about appropriate means of summative assessment for a 'full' multiple disciplinary module:

> *I think how we had the presentation and how we got to talk with the lecturers and how you got to question us, I think that should be an assessment, but then it doesn't really feel like it is finished. So I think some kind of individual or a separate smaller project towards the end, just to kind of tie it all in together. (Group 3)*

The perceived benefits of integrating components of group and individual assessment were also articulated by the tutors, specifically in helping to counter some of the issues around inequality of input that can arise from group work:

> *I think some kind of group presentation is very effective for the nature of the material, but it [assessment within a full module] would need to be longer than what was experienced in the pilot. But I remember us also talking about individual contribution, which is important to factor in a group project and group presentation because it is possible for certain individuals to end up doing an awful lot of the work and for some individuals to end up not doing very much of the work and receiving the same grade. So some thought would need to be given over to the form of the individual assessment. (Tutor 1)*

Previous studies have successfully applied a combination of group and individual approaches to assessing PjBL in sustainability education in both mono- and multiple disciplinary contexts (e.g. Lehmann et al., 2008; Nation, 2008), but ultimately the method(s) of assessment used should align with both the nature of the task and the abilities being developed (Kahn & O'Rourke, 2004). With respect to this study, a key aim of the immersive PjBL modules is to develop students' individual and group skills, therefore combining elements of group and individual assessment seems an appropriate strategy to adopt.

What types of support are required by first-year students engaging in multiple disciplinary PjBL?

Effective support for learning, in terms of both resources and faculty contact, is crucial to the successful implementation of PjBL (Spronken-Smith & Kingham, 2009). While the students generally perceived the delivery and content of the introductory session to be appropriate for their needs (Figure 1), when it came to actually beginning the task, their perceptions about their 'readiness' were more variable. This highlights the importance of making explicit the academic requirements of the task and expectations of the students, prior to them embarking on independent study (Stauffacher et al., 2006; Gavin, 2011). This raises again the dilemma of dealing with wicked problems: to what extent should instructors attempt to scaffold students' learning, which might detract from the 'authenticity' of the task, or leave them to find their own way?

Just as students can find the shift from traditional, transmissive-style teaching to active, experiential approaches such as PjBL challenging, so academic staff may also feel uncertain about their new role as facilitator, and the appropriate level of scaffolding to provide (Blumenfeld et al., 1991; Thomas, 2000; Joyce, Evans, Pallan, & Hopkins, 2013). Although the tutors made clear at the outset of the activity their willingness to provide

additional academic support, none of the students requested it. This partly reflects the 'non-typical' participants, i.e. motivated, self-selecting students who were prepared to discuss and work through any issues among themselves. However, the students also expressed some reticence around proactively contacting faculty involved in the project (including the academic tutors, project lead, and project researcher-evaluator), even though the academic tutors were reasonably well known to some of the students in each trial group:

> *And also I think, or suspect, that if it is not scheduled time [with faculty], people won't ask for it because I think that's always a problem... is that people don't tend to… to feel comfortable just dropping lecturers emails and things like that. (Group 2)*

In addition, both tutors expressed concern about the lack of contact and advocated building a greater degree of formal student support into the final module design, rather than putting the onus on students to request support on an ad hoc basis:

> *I was initially concerned about the lack of contact with the students and the fact that they might, that they might get a bit lost…..If we choose to run with the coal situation, then we would still need to deliver what [Tutor 1] delivered, and again, maybe that could be a lecture with slightly more information, longer. (Tutor 2)*

The mismatch between the tutors' expectation that students would seek additional contact, and the students' reluctance to do so, highlights the challenges that can emerge when the responsibility for learning and managing work is shifted from the academic tutors to the students (Danford, 2006; Donnelly & Fitzmaurice, 2005; Frank & Barzilai, 2004; Kolmos & de Graaf, 2007). Indeed, the suggestion by Tutor 2 that lectures could be used to deliver

additional student support, thereby contradicting the ethos of PjBL as student-centred and interactive, clearly demonstrates the extent of this challenge. However, the fact that all three groups did manage to successfully complete the activity without any additional tutor intervention indicates that, left to their own devices, first-year GEES students are entirely capable of working together to generate learning outputs in relation to complex sustainability issues. A useful strategy might therefore be to provide strong scaffolding in the early stages of the project, which is reduced as students gain in confidence and develop self-reliance in their learning (e.g. Stauffacher et al., 2006; Bell, 2010). This is considered further in a later section, in relation to the application of the study findings to module design and delivery.

It is not just academic support that students require – they also need to be supported in developing professional and employability skills, highlighted in previous studies as an important outcome from the application of PjBL to environmental and sustainability issues (e.g. Meehan & Thomas, 2006; Cheung & Chow, 2011, Brundiers & Wiek, 2013; Kricsfalusy et al., 2016). Key aspects of this trial PjBL activity were intended to mimic authentic professional scenarios, i.e. working in a multiple disciplinary team to deliver a pre-defined output relating to a complex and ill-defined issue, within a fixed timescale. Students recognised the impact of the trial PjBL activity on developing their broader transferable skills, and the relevance of skills such as organisation, time management and effective communication in terms of the professional workplace. In particular they perceived that they had gained important skills such as the ability to explain issues or concepts clearly and simply using non-technical language, listening to and learning from others outside of one's own discipline, and co-ordinating group work tasks to meet deadlines. Gaining experience in multiple disciplinary team work in their first-year exposes students to different viewpoints, and doing so highlights the importance of accommodating diverse perspectives. It also

enables them to gain confidence in talking to and working with unfamiliar people, and provides an opportunity to practice assertiveness in expressing their own opinions:

> *I think I feel a lot more comfortable to just to talk to people I don't know about something. Like, when we were working together, it was quite a big task to be put with people you have never met before necessarily, to produce something that has got to be of quite a good standard. And it's actually something that you probably find in the workplace, you know, being put together…and you are actually getting paid for that. (Group 1)*

These skills are important if students are to compete in a globalised graduate employment market (Dacre Pool & Sewell, 2007), so framing problems and questions within authentic professional contexts to support their development (e.g. Danford, 2006; Meehan & Thomas, 2006; de Graaf & Kolmos, 2007) seems essential in the design of PjBL activities aimed at first-year students.

To what extent are extracurricular trial activities useful in informing curriculum design and delivery?

A characteristic of this particular study was the use of trial activities to gain some insight into the pedagogic potential of PjBL, prior to a phase of curriculum development. The insights emerging from this exploratory study support findings from previous investigations that PjBL offers considerable potential as a pedagogic approach for sustainability education generally (e.g. Brundiers & Wiek, 2013; Wiek et al., 2014), and also in the GEES disciplines specifically. GEES disciplines are cognate in the sense that they share broad concepts (e.g. interactions of humans with their environment) and pedagogies (e.g. active and experiential

589 learning), include sustainability as a fundamental part of their curricula, and are considered
590 'interdisciplinary' in their own right (QAA, 2014b, c). Despite these similarities, however,
591 they are distinct in terms of their respective knowledge-bases, methods and philosophies. The
592 potential breadth of knowledge and experience when bringing together learners from across
593 these disciplines is, therefore, considerable. This is best reflected in the finding that, although
594 restricted to a single research question, the three trial PjBL activity groups approached the
595 task differently and produced distinct outcomes. Choice in project topic is advocated in the
596 literature on democratic (Von Kotze & Cooper, 2000) and pedagogic (Bell, 2010) grounds,
597 but when applied to the GEES disciplines, limiting topic choice does not appear to limit the
598 potential for creative thinking. The application of PjBL to this particular combination of
599 disciplines, heretofore unreported, therefore seems well placed to develop potentially
600 innovative solutions to complex sustainability issues.
601 The design of the trial PjBL activity described here was informed by both educational
602 theory and practice (Brundiers & Wiek, 2013), and further guided by initial perceptions of
603 GEES students and academic staff with respect to the benefits and challenges of this
604 pedagogic approach (Harmer and Stokes, 2016). The activity was experiential in nature,
605 enabling students to actively engage with a complex sustainability issue through a cycle of
606 experiencing, reflecting, drawing conclusions and planning for future experiences (Kolb,
607 1984). It was also evident, from the mind maps that the students produced, and their
608 reflections on the process, that the trial PjBL activities had facilitated the construction of new
609 insights and understandings, through a combination of social interaction and the integrating
610 of knowledge from multiple disciplines. The extent to which the experience was
611 transformative is unclear, however, and merits further investigation.
612 Despite the limitations to this study outlined previously, the opportunity to 'have a go'
613 proved extremely valuable in providing insight into the characteristics of PjBL likely to be

appropriate for delivering sustainability education to first year students learning in a multiple disciplinary context, specifically in relation to question format, appropriate means of assessment, the extent to which learning needs to be scaffolded and supported, and the value to the students of learning in authentic, experiential contexts. It also provided an opportunity for faculty to engage with this new teaching context, and to consider the implications for developing their own practice.

APPLICATION OF THE STUDY FINDINGS TO CURRICULUM DEVELOPMENT

Recognizing the limitations inherent in the trial PjBL activities, key findings from this evaluation were applied to the final design of the four-week module 'Climate Change and Energy' introduced in the academic year 2015/16 (Table 2), and delivered/facilitated mainly by faculty from the School of Geography, Earth and Environmental Sciences, with some contributions from specialists from elsewhere within the university, and from external organizations (Table 3). This module aims to provide students with the knowledge and skills to:

- Understand the scientific evidence for climate change;
- Evaluate information on greenhouse gas reduction measures;
- Think critically, creatively and strategically about how greenhouse gas emission reductions can be implemented.

The main changes to the original trial activity design involved 1) introducing limited project choice; 2) scaffolding and supporting learning (particularly in the early stages of a project); and 3) providing consistent formative feedback. Students participating in the trial activities were provided with a single project topic, i.e. there was no topic choice. While this did not

cause any apparent issues during the trial activities, it was unclear how removing the choice of project topic entirely would scale-up to a larger population (i.e. a cohort of ~60 students). To mitigate this, a limited range of project options focused on identifying solutions to reducing global carbon emissions were introduced (Socolow and Pacala, 2006) – this also provides a more authentic context for PjBL than simply undertaking research. To better scaffold learning, specific attention is paid during the introductory lecture and first interactive workshop to signposting sources of information, promoting team building through interactive exercises (Table 4), and facilitating discussions within groups about how to begin progressing their ideas. The introductory lecture introduces a range of techniques, termed the 'Strategic Thinking Tool Kit' (Table 3), that can be applied to project planning and decision making, e.g. mind mapping, Plus Minus Interesting (PMI), and Other People's View (OPV) (Table 4). Students then receive guidance during subsequent workshop sessions in how to make effective use of these techniques. Note that it is only during the first introductory lecture that learning support is addressed – after this point the lectures focus on delivery of scientific content, with the provision of support, and facilitation of learning, shifted to the interactive workshops. Rather than needing to proactively seek out feedback, formative feedback is provided consistently throughout these interactive workshops at both group and individual level.

Since the module was first delivered in January 2016, the majority of the original module design and delivery characteristics have remained largely unchanged. This demonstrates the value to the curriculum designers of trialling the activity, particularly in enabling the main potential issues for students and faculty to be identified, and mitigated. However, feedback from the first end-of-module student evaluation questionnaire suggested that students did not find the module academically challenging (Figure 2). Specifically, students requested more lectures, and better linkage between lectures and the assessment task.

To address this, additional lectures relating specifically to the science of climate change were introduced, lecture content focused more explicitly towards the topics of assessment (i.e. reducing global carbon emissions), and students set more time-limited, focused tasks to be completed during workshop sessions. Although perceptions of academic challenge have increased since these changes were implemented (Figure 2), it is interesting that students have requested more lectures (i.e. didactic, teacher-centred instruction), and the faculty have responded by providing more lectures. This implies a perceived link between academic rigor and style of instruction that merits further investigation. It also raises important questions about the level of support needed by faculty when engaging with more student-centred pedagogic approaches.

One critical aspect of the students' learning experience requiring further exploration is whether, and to what extent, this approach to PjBL succeeds in being 'transformative' in terms of empowering learners to challenge their beliefs about how the world works (Sipos et al., 2008; Palma & Pedrozo, 2016). This could be achieved by having students critically reflect on how their participation in multiple disciplinary PjBL has changed the ways in which they experience and interpret the world around them, and helped them to develop the skills in autonomous thinking characteristic of transformative learning (Mezirow, 1997).

CONCLUSIONS

We investigated how PjBL could be applied to learning about complex sustainability issues in a multiple disciplinary context, by designing and trialling a PjBL activity with student volunteers. The main conclusions to emerge from this study are:

- PjBL offers considerable potential as an approach to delivering sustainability education to first-year undergraduates in GEES disciplines;
- Multiple disciplinary PjBL provides an engaging context for learners to develop both their professional and academic skills;
- Offering limited project choice need not stifle innovative thinking, and can generate a diverse range of learning outputs;
- Learning needs to be adequately supported and scaffolded, particularly during the early stages of a PjBL activity, and preferably in interactive contexts;
- The assessment of PjBL activities should aim to address both individual and group competencies;
- Further investigation is necessary into the transformative potential for multiple disciplinary PjBL.

Arguably the most important outcome, at least for the project team, has been recognizing the value in trialling a new pedagogic approach, in order to gain some insight into the potential issues for both learners and instructors. This proved invaluable to the wider curriculum development process and, although much still remains to be learned, is an approach that we would encourage practitioners to adopt.

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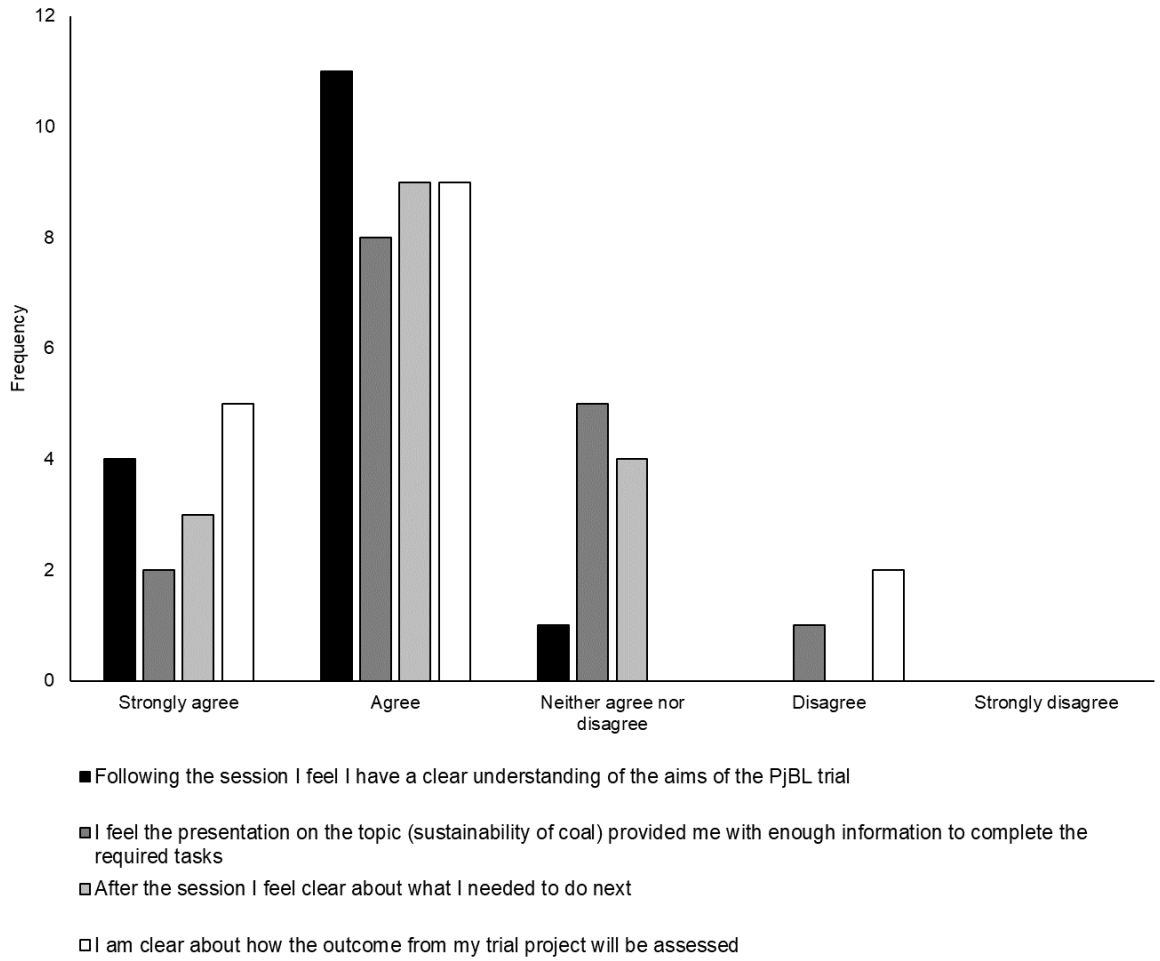
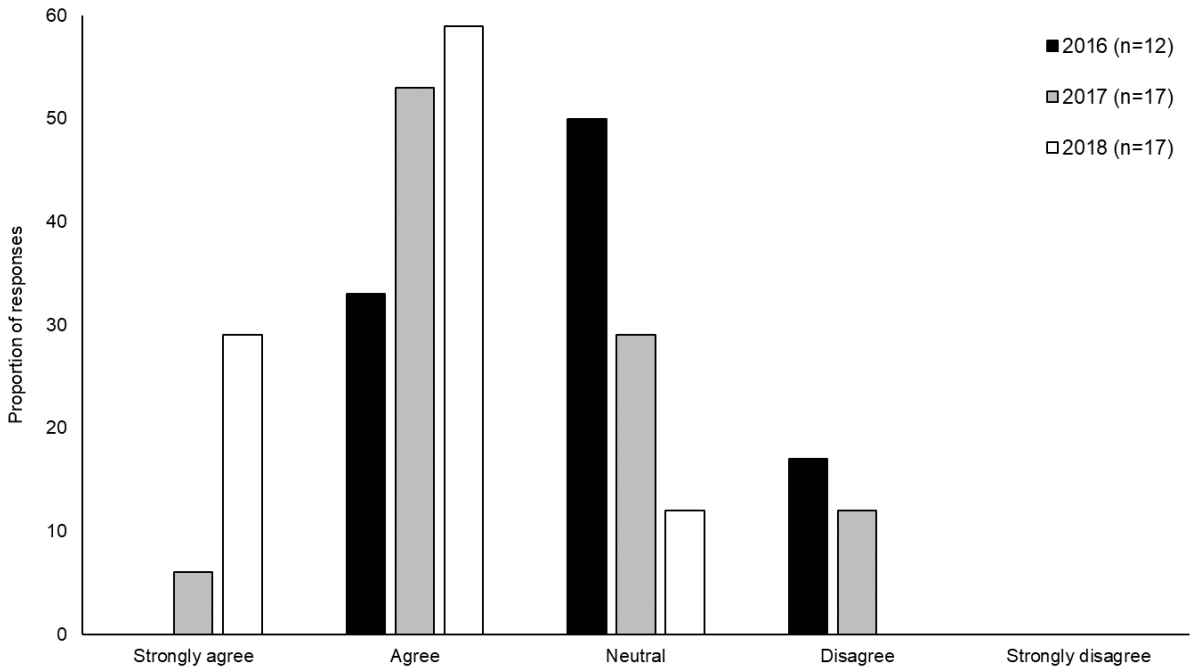


Figure 1. Students' perceptions of the introductory session as measured by Likert scale responses to the four questions stated. No responses were recorded in the 'strongly disagree' category.

977



978

979 Figure 2. Student responses to the statement in the module evaluation questionnaire "The module was
980 academically challenging". The questionnaire response rates were 19% for 2016, 32% for 2017 and
981 31% for 2018. Note that, while students are strongly encouraged to complete the questionnaire,
982 ultimately this is optional.

983

Table 1. Suggested programme of activity for student participants

Week	Task / activity	Owner	Time (hours)
1	Explore project resources on Moodle – familiarise with topic	Students	1
	Introduction and initial briefing	Faculty	1
	Preliminary team activity: − Introductions and ice-breaker − Negotiate teamworking contract − Identify task requirements − Initial mind map − Allocation of individual tasks / workload	Students	2
	Commence with tasks	Students	3
2	Drop-in support session with faculty by request	Students	1
	Review group progress	Students	1
	Continuation of tasks		3
3	Synthesis of group findings and compilation of mind map	Students	1
	Compile individual summary of findings		1
	Presentation of project outputs and debrief	Faculty	1

989 Table 2. Summary of the main design and delivery characteristics for the trial PjBL activity and final
990 module.
991

Characteristic	Trial PjBL activity	Final module design
Group size and allocation	Allocated to multiple disciplinary teams of 5-6 students.	Allocated to multiple disciplinary teams of 4-5 students.
Team building	Introduction to group working (individual strengths and weaknesses, negotiating a 'group work contract') and initial 'brainstorming' activity.	No change.
Project topic	No choice: students provided with one research question.	Restricted choice of project topics focused on strategies to achieve an annual reduction of one gigatonne in global carbon emissions (based on Socolow & Pacala, 2006).
Content delivery	Introductory session (1hr) with online resources available via a Digital Learning Environment (Moodle)	Combination of faculty-led lectures (2 hours duration) and tutor-facilitated workshops (2 hours duration). Invited lectures delivered by guest speakers to emphasise the relevance to real world problems.
Learner support	Online resources available via a Digital Learning Environment (Moodle); students invited to contact academic tutors if they required help or guidance with the task.	Introduction to 'Strategic Thinking Tool Kit' to support interactive group learning, mind mapping and decision making provided during introductory lecture, and support applying techniques provided during interactive workshops.
Formative feedback	No formal feedback provided, students invited to contact academic tutors if they required help or guidance with the task.	Feedback on group and individual project ideas delivered during weekly interactive workshops facilitated by faculty, and peer-feedback through informal presentation of project ideas to other students.
Summative assessment	Research findings and recommendations summarized on group mind maps (subject of formative feedback in final module).	1) a group poster focused on a specific strategy to reduce greenhouse gas emissions, and presented at a public exhibition (50% of module mark); 2) an individual report incorporating critical evaluation of the proposed emissions strategy (50% of module mark).

992

993

994 Table 3. Schedule of learning for the 'Climate Change and Energy' module.
995

Week	Session	Topic	Session led by
1	Lecture	Module overview Introduction to the Strategic Thinking Tool Kit (to aid project planning)	1) Module leader (environmental science faculty; Tutor 2 in this study); 2) Guest speaker and expert on strategic thinking and project planning
	Lecture	Sustainability	1) Module leader; 2) Educational development specialist with expertise in sustainability
	Lecture	Climate Change Science	Module leader
	Workshop 1	Introduction to project teams and teambuilding exercises Using the Strategic Thinking Tool Kit to work through decarbonisation strategies	Workshop tutors (faculty with expertise in geography, geology and environmental science); typically 12-15 students per workshop (3-4 project teams)
	Lecture	Global Climate Change Policy	Geography faculty with specific expertise
2	Lecture	Global Energy Use	Geology faculty with specific expertise
	Tutorial	What makes a good poster and clarification of assessment requirements	1) Module leader; 2) Support staff member with expertise in poster prep
	Workshop 2	Group project scoping and planning in preparation for assessed poster conference	Workshop tutors
	Lecture	Project Ideas & Climate Change Impacts	Module leader
3	Seminar	Review and feedback on poster design	1) Module leader; 2) Support staff member with expertise in poster prep
	Workshop 3	Planning and development of individual project proposals	Workshop tutors
	Lecture	Climate Change Solutions	Module leader
	Poster Conference	Presentation and assessment of group posters	Guest presentations by representatives of local environmental action groups
4	Workshop 4	Formative feedback and guidance on individual project proposals	Workshop tutors
	Lecture	Climate change discussion and Poster Feedback	Module leader

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998 Table 4: Example tools to support student learning.

Tool	**Activity**
Teambuilding: think-pair-share	Students work individually to write down their own strengths and weaknesses, then discuss these first in pairs, then as a group. This enables students to identify the range of strengths (e.g. organization, public speaking skills), and weaknesses (e.g. poor timekeeping, procrastination) within their group.
Teambuilding: group work contract	Building on the think-pair-share exercise, groups think about the possible problems that may arise during group work, and the ways in which these can be mitigated. Groups collaborate to compile answers to a range of questions relating to behaviour, communication, leadership, engagement, and conduct, and which form the basis for a 'group work contract'.
Critical thinking: Plus, Minus, Interesting (PMI)	A large sheet of paper is divided into three columns (headed P, M, and I) and used to record all of the positive, negative, and interesting points that the student / group can think of relating to a particular idea. They are then able to better to appraise their ideas by evaluating the relative strengths and weaknesses.
Critical thinking: Other People's View (OPV)	This builds on the PMI analysis by having a student / group consider the range of people that might be in some way affected by, or involved in, their idea, and 'stepping into their shoes'. Selecting one of these alternative viewpoints and running a second PMI from this alternative perspective provides valuable insights into the complexities of decision making where multiple stakeholders are involved.

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Supplement A(i): Interview questions used in follow-up interviews with student participants

- What made you interested in taking part in the trial?
  - Was it what you expected?
  - If not, how did it differ from your expectations?
  - Which aspects of the trial did you find enjoyable?
  - Were there aspects of the trial which you did not enjoy or found difficult?

- How did you feel about the choice of project topic?
  - Would you have liked to have had a say in the choice of topic or project?
  - Would you have preferred a topic with a more hands-on/practical element?

- How did you find the workload (bearing in mind that you are having to do this work over and above your ongoing modules)?
  - Were you clear about what you were expected to produce?
  - Was the timeframe long enough for what you needed to do?
  - Would you have liked to have more choice over the type of output from the project?

- Were you clear about how the project would be assessed?
  - Did you feel that the assessment process fairly captured your individual input as well as the group's overall achievement?

- How did you find the group work?
  - What about the size of the group? Was it too big? Too small?
  - Were there any difficulties experienced within the group?
  - How did you deal with these?
  - Do you think you had sufficient preparation for the group work?
  - Would you have liked more group facilitation? More time to gel as a group?
  - Do you think a session in group working would have been useful at some stage during the project?

- How did you find working with people from other disciplines?
  - What advantages do you think there are to working with students from other disciplines?
  - What drawbacks or difficulties are there involved with working with people from other disciplines?

- Did people take on different roles within the group?
  - If so, how was this decided?
  - What was your role?
  - Were you happy with your role?
  - Do you think it would have been helpful to have had roles pre-assigned?

- How useful did you find the online resources?
  - Are there any other resources you would have found helpful?

- Would you have liked more staff input?
  - At what stages?
  - What type of input?

- What do you think you gained academically from taking part in the project?

- Do you think you gained non-academic skills from taking part in the project and if so, what were they?

- How could the activity design could be improved?

Supplement A(ii): Interview questions used in follow-up interviews with academic tutors

- How do you feel the trials went?
  - What went well?
  - What challenges did you identify?
  - Was there anything that came out of the trials that was unexpected?

- How did you feel about the choice of question?
  - How feasible do you think it might be for the students to have a say in the choice of topic?

- What were the advantages or disadvantages of working with students from other disciplines?

- Do you think there was a need for more preparation or facilitation of the group work?

- After listening to the students' feedback on their group work experience, what are your thoughts about group composition?

- The students had the opportunity to contact the academic tutors for more help during the project, but they chose not to.
  - Do you have any ideas why that might have been?
  - Do you think there was a need for more staff input?
  - At what stages? What type of input?

- How would you describe your role as a staff member on the project?
  - How different was this from your normal style of teaching?
  - How did you like this approach?

- Having listened to the three groups, what are your feelings now about the types of assessment that may be appropriate for the module?

- How do you feel that the assessment process can fairly capture individual input as well as the group's overall achievement?

- What did you feel about the quality of the work produced by the students?

- Do you think there are other non-academic skills that the students gained from taking part in the project and if so, what were they?

- How useful do you think the trials were in helping plan future curriculum developments?

- What have you learned about your own practice from the trials?

1099 Supplement B: Main emergent themes and example codes

Theme	**Example codes**
Perceptions of multiple disciplinary learning	Benefits of multiple disciplinarity Challenges of multiple disciplinarity
Activity design	Breadth of topic Group selection and size Question choice Question wording Methods of assessment Tutor expectations / concerns
Activity implementation	Task allocation Time management Group working Independent working Use of IT Working outside of own academic discipline Tutor perspectives of student approach
Learning outcomes	Academic learning (knowledge and skills) Different ways of thinking Social learning and interaction Transferable and employability skills Reflective learning
Learner support	Learning resources Introductory workshop Scaffolding of activities Tutor support
Student personal perspectives	Enjoyment of the project Interest in the topic Reasons for participating Social benefits
Implications for curriculum design	Planning for future modules Development of competencies for next academic year

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